

SPECIFICATION

TITLE OF INVENTION

[0001] Name of applicant: Vincent Craig Olsen

[0002] Citizenship of applicant: United States of America

[0003] Residence of applicant: 1618 Lenz Lane; Boise, ID 83712; USA

[0004] Title of the invention: A method and computer controlled apparatus for bending elongate material utilizing a pure bending moment.

CROSS-REFERENCE TO RELATED APPLICATIONS

[0005] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

[0006] Not applicable.

REFERENCE TO SEQUENCE LISTING, A TABLE, OR A COMPUTER PROGRAM LISTING COMPACT DISK APPENDIX

[0007] Not applicable.

BACKGROUND OF THE INVENTION

[0008] 1. Field of the Invention: The present invention relates generally to elongate material bending machines and more specifically to tube benders, pipe benders, rod benders, and structural and passageway part forming and shaping devices where the strength properties of the bent or formed product is of concern.

[0009] 2. Description of the Prior Art: Elongate material benders have been available in the prior art for many years. Most benders fall into one of the following categories or types of benders: ram style benders, compression type benders, rotary draw type benders, roll type benders, and moment benders.

[0010] Ram style bending usually utilizes bending dies and creates angles in the material by advancing a contact located centrally on one side of the material toward two other contacts located distally on the other side of the material.

[0011] Compression type bending creates bends by supporting material internally and or externally while forcing the material around and onto a stationary fixed radii tool or die with a movable pressure bending die. A mandrel can be used to support the material to help keep it from collapsing during the bend process.

[0012] Rotary draw type bending deforms material by clamping onto the material and then drawing the material around and onto a rotating die of fixed radii. The material is supported in the bend process by a stationary or sliding pressure die. A wiper die is used to reduce the

amount of crimping caused in the material. The material is bent to different angles by controlling the degree of rotation of the rotary die.

[0013] Roll type bending deforms material by using lateral material movement while a center roller is displaced perpendicularly toward the lateral moving material creating a pressure parallel to the cross section such that desired angles are achieved.

[0014] Moment benders deform material by creating a bending moment within the material. A bending moment is created in a section of material between two torque couples. A torque couple can be created by two parallel but opposite forces that are separated a distance perpendicular to the forces. Thus, a bending moment can be created between two centrally located supports that oppose two distally located forces.

[0015] These methods of bending employ mainly shear stresses to deform the elongate material. Shear stress is in a direction perpendicular to the longitudinal axis of the elongate material. The shear stresses deform the material by essentially forcing the cross section of the material to be displaced in a direction perpendicular to the longitudinal axis with respect to adjacent cross sections. A bending moment creates bending stress in a direction along the axis of the elongate material. The bending stress is tensile along the outside of the bend and compressive along the inside of the bend. The bending stress encourages the material to be displaced along the length of the axis of the bending section rather than transverse to it. Experts familiar with the deformation modes of materials will note that material that is deformed with a bending moment has less stress concentrations than material that is deformed with shear stress.

Since it has less stress concentrations, material deformed with a bending moment is stronger than material deformed with shear stress. A pure bending moment is a bending moment that evenly distributes the bending stress over the cross section of the material such that the deformation and stress concentrations are evenly distributed throughout the bending section. Experts familiar with the modes of material deformation will note that a pure bending moment creates the least amount of stress concentrations in a bend and therefore produces the strongest bends. The other major problem with most of the aforementioned bending methods is that they often focus the majority of the deformation to a single location. When the bending stress is not evenly distributed throughout the material, excessive stress concentrations are formed which reduce the strength characteristics of the bent material.

[0016] The disadvantage of the current state of the art moment benders is that they do not employ a pure bending moment and that the material is not allowed to bend naturally in response to the applied couples since the linear displacement between the couples is not reduced in a manner such that the material can naturally deflect and deform. This introduces shear stresses and uneven bending stress distributions which cause excessive stress concentrations within the bent elongate material.

BRIEF SUMMARY OF THE INVENTION

[0017] The present invention entails a method and a computer controlled machine that utilizes low contact stress material interfaces to apply a pair of torque couples to an elongate material to create a pure bending moment which distributes the bending stress evenly along the axial length and across the cross section of the bending section. The material interfaces are configured such

that the linear displacement between the couples is reduced at the rate required during the bending process to accommodate the changing geometry of the bending section and to constantly maintain a pure bending moment such that the elongate material can naturally bend in response to only the pure bending moment. The computer controlled machine bends elongate material while minimizing stress concentrations caused by bending work and greatly reduces or eliminates stress concentrations and surface deformations caused by material interface contact stresses. The computer controlled machine accurately and predictably produces bent elongate material sections with greater strength properties.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

[0018] FIG. 1 is a diagram depicting the method bending.

[0019] FIG. 2 is a front page perspective view of the complete elongate material bender machine including a depiction of the relationship between the user interface, the computer programs, the control circuitry, and the elongate material bender assembly.

[0020] FIG. 3 is an exploded perspective view of the elongate material bender assembly.

[0021] FIG. 4 is an enlarged exploded perspective view of the stationary bender assembly.

[0022] FIG. 5 is an enlarged exploded perspective view of the rolling bender assembly.

[0023] FIG. 6 is an enlarged exploded perspective view of a material interface assembly.

[0024] FIG. 7 is an enlarged exploded perspective view of the rolling bender frame assembly.

[0025] FIG. 8 is an enlarged exploded perspective view of the front roller assembly.

[0026] FIG. 9 is an enlarged exploded perspective view of the rear roller assembly.

[0027] FIG. 10 is a circuit diagram of the control circuitry.

[0028] FIG. 11 is a flowchart depicting the structure of the elongate material bender machine control program.

DETAILED DESCRIPTION OF THE INVENTION

[0029] FIG. 1 is a diagram depicting the method of bending. An elongate material 1 is subjected to two couples 2 that create a pure bending moment. The section of elongate material 1 between the two couples 2 is the bending section 3 over which the bending moment is applied. As the two couples 2 are increased in magnitude and rotationally displaced, the bending section 3 deforms in a manner predictable with engineering plasticity theory. As the bending section 3 deforms, the couples 2 are linearly displaced toward each other, as represented by the arrows 4 pointing toward each other, to accommodate the changing geometry of the bending section 3 and to continually maintain a pure bending moment within the bending section 3.

[0030] FIG. 2 is a front page perspective view of the complete elongate material bender machine including the elongate material bender assembly also pictured in FIG. 3, the digital user interface 39, the elongate material control bender program 37 also depicted in FIG.11, the bend formula calculating program 38, and the control circuitry 36 also depicted in FIG.10. The digital user interface 39 is designed such that the user can easily input the elongate material and cross-section characteristics and the desired final geometric bend dimensions and can receive feed back from the bend formula calculating program 38 and the elongate material bender control program 37. The bend formula calculating program 38 and the elongate material bender machine control program 37 are preferred to be configured as subprograms of a single computer control program, but can be arranged as separate programs that work together to accomplish the same tasks. Based on the input data, the bend formula calculating program 38 uses geometric and engineering plasticity theory calculations and references a database of correction factors for specific materials to determine what magnitude of bending moment is required to bend the elongate material 1, the required rotational displacement of the bending moment producing couples 2 to accomplish the desired plastic bend while taking into account elastic relaxation, and the amount of linear displacement of the rolling bender assembly 8 that will take place if the bending process is successful. The geometric and plasticity theory calculations are well established and should be known to those that are expert in the modes of material deformation. The bend formula calculating program 38 also will evaluate the performance of the bend operation and then reference and update the database of correction factors for specific materials. The bend formula is transferred to the elongate material bender control program 37 that then controls the functions of the elongate material bender machine. To aid in its control functions, the elongate material bender control program 37 acquires elongate material bender machine

positional data through axle rotational position sensors 35 attached to the gearmotors 10 and the linear position sensor 34 attached to the rolling bender assembly 8. The elongate material bender control program 37 sends the bend performance data to the bend formula calculating program 38 for bend performance evaluation. The control circuitry 36 allows the elongate material bender control program 37 to interface with the gearmotors 10, axle rotational position sensors 35, and linear position sensor 34 of the elongate material bender machine and provides the required power circuits.

[0031] FIG. 3 is an exploded perspective view of the elongate material bender assembly. The stationary mount bolts 5 attach the stationary bender assembly 6 to the support rail 7. The support rail 7 is designed such that it provides the structural strength and stiffness required to support the functions of the elongate material bender machine. The support rail 7 also provides a smooth surface on the top and bottom of the rail so that the rollers 27 can easily roll along the support rail 7 surfaces. The stationary bender assembly 6 is also pictured in FIG. 4. The rolling bender assembly 8 is also pictured in FIG. 5. The stationary bender assembly 6 and the rolling bender assembly 8 each have a material interface assembly 15 that securely holds the elongate material 1 and that each apply a couple 2 to create a pure bending moment in the bending section 3 between the two material interfaces assemblies 15. As the couples 2 are applied and the bending section 3 deforms, the rolling bender assembly 8 rolls along the support rail 7 toward the stationary bender assembly 6 as indicated by the arrows 4 in FIG. 1 to accommodate the changing geometry of the bending section 3.

[0032] FIG. 4 is an enlarged exploded perspective view of the stationary bender assembly 6. The stationary bender mount 9 is attached to the support rail 7 by the stationary mount bolts 5. The stationary bender mount 9 is designed such that it will provide the required structural strength and stiffness required to support the functions of the machine and also has mounting holes positioned such that the components can be mounted properly. A gearmotor 10 with an attached axle rotational position sensor 35 is held to the stationary mount 9 and a gearbox 12 by motor mounting bolts 11. The gearbox 12 increases the torque of the gearmotor 10 and is attached to the gearmotor 10 by the motor mounting bolts 11 and to the stationary mount 9 by gearbox mounting bolts 13. The high torque output axle of the gearbox 12 is coupled to the material interface assembly 15 in such a way that all of the torque from the gearbox 12 can be transferred to the material interface assembly 15 with minimal torsional deflection of the assembly. The preferred embodiment of the coupling consists of perpendicular holes in the gearbox 12 high torque output axle that align with holes in the material interface assembly 15 which is held in place with the material interface mounting bolts 14 inserted through the holes. The spring mount bolt 30 bolts to the stationary bender mount 9 at a vertical level equal to the material interface assembly 15 such that, if required, a light weight spring can be attached between the stationary bender assembly 6 and the rolling bender assembly 8 to help balance the loads on the two bender assemblies and to encourage the rolling bender assembly 8 to move toward the stationary bender assembly 6 at the initiation of the bend, without introducing extraneous forces of sufficient magnitude to create anything other than a pure bending moment stress in the bending section 3. The material interface assembly 15 is also pictured in FIG. 6 and is designed to transfer the couple 2 by rotating clockwise as viewed when looking at the four material interface bolts 19 during the bend process.

[0033] FIG. 5 is an enlarged exploded perspective view of the rolling bender assembly 8. The rolling bender frame assembly 16 is also pictured in FIG. 7 and is the main structural support to which the material interface assembly 15, lateral position sensor mount 31, spring mount bolt 30, front roller assembly 17, and rear roller assembly 18 are attached. The material interface assembly 15 is mated to the high torque output axle of the gearbox 12 of the rolling bender assembly 16 by two material interface mounting bolts 14. The material interface assembly 15 is also pictured in FIG. 6 and is designed to transfer the couple 2 by rotating counterclockwise as viewed when looking at the four material interface bolts 19 during the bend process. The front roller assembly 17, also pictured in FIG. 8, and the rear roller assembly 18, also pictured in FIG. 9, are attached to the rolling bender frame assembly 16 by two pillow block bearings 24 each. The front roller assembly 17 and rear roller assembly 18 roll along the support rail 7 and hold the rolling bender assembly 8 to the support rail 7 to counter the rotational reaction forces created by the bending section 3 resisting deflection. The front roller assembly 17 and rear roller assembly 18 are designed such that they provide the required structural strength and stiffness to support the rolling bender assembly 8 during the bending process while allowing the rolling bender assembly 8 to easily roll toward the stationary bender assembly 6 on rollers 27 that roll along the support rail 7. The linear position sensor mount 31 is attached to the rolling bender assembly 8 with two linear position sensor mount mounting bolts 32. The linear position sensor mount 31 provides a secure mount for the linear position sensor 34. The linear position sensor 34 is attached to the linear sensor mount 31 by linear position sensor mounting bolts 33. The linear position sensor 34 accurately detects the linear position of the rolling bender assembly 8 along the support rail 7 with respect to the stationary bender assembly 6. This information allows the elongate material

bender control program 37 to detect if the work piece was set up properly, to control the functions of the bend, and to evaluate the performance of the bend operations. The spring mount bolt 30 attaches to the rolling bender frame 9 at a vertical level equal to the material interface assembly 15 such that, if required, a light weight spring can be attached between the stationary bender assembly 6 and the rolling bender assembly 8 to help balance the loads on the two bender assemblies and to encourage the rolling bender assembly 8 to move toward the stationary bender assembly 6 at the initiation of the bend, without introducing extraneous forces of sufficient magnitude to create anything other than a pure bending moment stress in the bending section 3.

[0034] FIG. 6 is an enlarged exploded perspective view of a material interface assembly 15. The material interface frame 22 provides the structural strength and stiffness required to transfer the torque from the bender assemblies to the elongate material 1 with minimal material interface assembly 15 deflection. This allows the rotational displacement of the couples 2 transferred by the material interface assemblies 15 to be more easily measured by the rotational position sensors 35 connected to the gearmotors 10. The material interface frame 22 has holes drilled such that it can be coupled to the high torque output axle of the gearboxes 12 by two perpendicular material interface mounting bolts 14. The material interface frame 22 has two extended prongs that transfer the torque of the bender assemblies to the elongate material 1. The material interface insert 21 is to be fabricated out of a material, such as nylon, that is softer than the elongate material 1 and is to be designed with a minimal diameter or cross-section and sufficient length such that the contact stresses between the material interface insert 21 and the elongate material 1 will be reduced to less than the yield strength of the elongate material 1. The material interface insert 21 is designed to act like a cushion sandwiched between the material interface frame 22

and the elongate material 1, and in this capacity, it may be subject to excessive wear and may be designed to be disposable. The material interface insert 21 is designed to fit snugly within the prongs of material interface frame 22 and securely around the elongated material 1 such that the pure bending moment created by the stationary bender assembly 6 and the rolling bender assembly 8 is efficiently transferred to the elongate material 1. The material interface insert 21 is designed to provide a snug grip on the elongate material 1 by having a slot completely through the interior side of the insert that faces the bender assemblies. This slot in the material interface insert 21 allows for a tight fitting material interface insert 21 to be flexed opened as the elongate material 1 is inserted into the material interface insert 21. After the elongate material 1 is properly positioned, the material interface insert 21 is then inserted into the material interface frame 22 and attached with the four material interface bolts 19. As the material interface bolts 19 are tightened, the material interface insert 21 is squeezed into the material interface frame 22 causing the slot in the material interface insert 21 to close more tightly and also providing a tighter grip on the elongate material 1. The material interface stiffener 20 is attached to the end of the material interface insert 21 and to the end of the material interface frame 22 by the material interface bolts 19 and provides an added level of stiffness and resists distortion of the material interface frame 22 when it is under load. The material interface assembly 15 is a low contact stress method of transferring the couples 2 that produce the bending moment to the elongate material 1 in a way that greatly reduces or eliminates surface deformations and stress concentrations inherent to current state of the art material interfaces.

[0035] FIG. 7 is an enlarged exploded perspective view of the rolling bender frame assembly 16. The rolling bender frame 23 is designed such that it provides the necessary structural

strength and stiffness, as well as mounting holes in the proper locations, to support the components attached to it throughout the bending functions. The gearmotor 10, with an attached axle rotational position sensor 35, is attached to the rolling bender frame 23 and the gearbox 12 by the motor mounting bolts 11. The gearbox 12 increases the torque of the gearmotor 10. The gearbox 12 is also attached to the rolling bender frame 23 by the gearbox mounting bolts 13 in such a way that the high torque output axle of the gearbox 12 extends out of a hole in the rolling bender frame 23. The pillow block bearings 24 are attached to the rolling bender frame 23 by the pillow block mounting bolts 25 over holes in the rolling bender frame 23 and provide pivot points for the front roller assembly 17 and the rear roller assembly 18.

[0036] FIG. 8 is an enlarged exploded perspective view of the front roller assembly 17. The front roller frame 28 is designed such that it has the required structural strength and stiffness, as well as mounting holes in the proper locations, to support the rolling bender assembly 8 throughout the bending functions. The rollers 27 are arranged such that they will rest on the top surface and on the bottom surface of the support rail 7 in a manner that will resist the reaction forces produced by the bending section 3 resisting deflection. The roller assembly support axle 26 attaches the front roller frame 28 to the pillow block bearings 24 that are attached to the rolling bender frame 23 and is designed to have sufficient strength and stiffness.

[0037] FIG. 9 is an enlarged exploded perspective view of the rear roller assembly 18. The rear roller frame 29 is designed such that it has the required structural strength and stiffness, as well as mounting holes in the proper locations, to support the rolling bender assembly 8 throughout the bending functions. The rollers 27 are arranged such that they will rest on the top

surface of the support rail 7 in a manner that will resist the reaction forces produced by the bending section 3 resisting deflection. The roller assembly support axle 26 attaches the rear roller frame 29 to the pillow block bearings 24 that are attached to the rolling bender frame 23 and is designed to have sufficient strength and stiffness.

[0038] FIG. 10 is a circuit diagram of the preferred embodiment of the possible configurations of the control circuitry 36. The two gearmotors 10 are each connected to four transistors T1 arranged in an H-bridge configuration. The transistors T1 are also connected to power sources V1 and to an imbedded logic controller ILC1. The transistors T1 are protected against surges by diodes D1 in the configuration shown. The imbedded logic controller ILC1 has input or output pins which connect to the various components as shown. The imbedded logic controller ILC1 controls the functions of the machine by either reading the input of the pins or by controlling the output of the pins. The resistors R1 are connected in series between the imbedded logic controller ILC1 and the transistors T1. The grounds G1 connect the circuits to a common electrical ground. The green light LED1 and the red light LED2 are connected to the imbedded logic controller ILC1. The axle rotational position sensors 35 and the linear position sensor 34 are potentiometers connected to the imbedded logic controller ILC1. Resistors R1 and R3 are connected as shown in series between the position sensors and the imbedded logic controller ILC1. The imbedded logic controller ILC1 is connected to a power source V2.

[0039] FIG. 11 is a flowchart depicting the preferred embodiment of the elongate material bender machine control program 37. The flowchart shows the different logic loops that are used by the elongate material bender machine control program 37 and shows the sequence of events.

[0040] All components of this elongate material bender machine are to be designed to withstand the applicable stresses and resist deflection such that they perform as desired. All components are also to be designed to resist fatigue and corrosion and to survive and withstand mechanical and chemical degradation inherent to the industrial environment that this machine is to be used in with exception for the material interface insert 21 which will be designed to perform as a cushion and as such might be subject to accelerated fatigue failure and may be considered a disposable part. Standard materials and methods of manufacture will be used to fabricate all of the components with an emphasis on processes and materials that produce stiffer parts.

[0041] The bending operation starts with the user determining what the desired final geometric dimensions of the bent elongate material are. The user then uses the digital user interface 39 to interface with the elongate material bender machine and inputs the desired final geometric dimensions of the bent elongate material into the bend formula calculating program 38. The properties and characteristics of the specific elongate material 1 to be bent are also entered into the bend formula calculating program 38. The bend formula calculating program 38 then manipulates the input data using geometry and engineering plasticity theory calculations and referencing a database of material specific correction factors to determine the required couples 2, required linear placement of the material interface assemblies 15 on the elongate material before bending, and required rotational displacement of the couples 2 taking into account the elastic relaxation of the bending section 3 after the couples 2 are removed. The geometric and plasticity theory calculations are well established and should be known to those that are expert in the

modes of material deformation. The user then slides the elongate material 1 into the material interface inserts 21 and the material interface assemblies 15 are positioned the required linear distance apart and the material interface bolts 19 are tightened providing a secure, but low contact stress, grip on the elongate material 1. The bend formula is then transferred to the elongate material bender machine control program 37 that will verify that the machine and elongate material 1 were set up properly and then control the magnitude and rotational displacement of the couples 2 by controlling the gearmotors 10 and monitoring the axle rotational position sensors 35 and the linear position sensor 34. The elongate material bender machine control program 37 interfaces with the machine through the control circuitry 36. The control circuitry 36 provides all of the necessary power circuits, control circuits, and electrical connections to support the functions of the elongate material bender machine. The torque produced by the gearmotors 10 is greatly increased by the gearboxes 12, and the torque is then transferred through the low contact stress material interface assemblies 15 to the elongate material 1 in the form of couples 2 parallel to each other and parallel to the cross-section of the elongate material 1. The couples 2 are configured such that they create a pure bending moment in the elongate material 1 over the bending section 3. The pure bending moment is the only stress on the bending section 3 that creates deformation. In response to the pure bending moment, the bending section 3 deflects and deforms in a manner predictable with plasticity theory. At the initiation of the bend, the rolling bender assembly 8 may need additional linear support to resist the reaction forces of the bending section 3. This additional linear support can take the form of a spring strung between the stationary bender assembly 6 and the rolling bender assembly 8 attached to the spring mount bolts 30. The low contact stress material interface assemblies 15 that transfer the couples 2 to the bending section 3 securely grip the elongate

material 1 and as the bending section 3 deforms, the rolling bender assembly 8 is compelled to roll along the support rail 7 toward the stationary bender assembly 6 such that the material interface assemblies 15 linearly approach each other as depicted by the arrows 4 to accommodate the changing geometry of the bending section 3 and to continually maintain a pure bending moment. The elongate material 1 is displaced beyond the desired final geometric dimensions of the bend as prescribed by the bend formula calculating program 38 to take into account the elastic relaxation, or spring back, of the bending section 3 after the bending moment is removed. The material interface assemblies 15 are then rotated in the opposite direction until the elastic rebound is released. The elongate material bender control program 37 sends the final position data from the axle rotational position sensors 35 and the linear position sensor 34 to the bend formula calculating program 38 that then evaluates the performance of the bending operations and makes any required modification of the correction factor database. The finished work piece is then removed from the machine and the machine is reset. This produces a bend that has the theoretical minimal amount of stress concentrations from the bending process and no, or minimal, surface deformations and stress concentrations from the contact stress from the material interface assemblies 15.

[0042] The present invention thus provides a technique for bending elongate material utilizing a constantly pure bending moment and allowing the elongate material to freely bend in response to the pure bending moment. This type of bending produces bends with the theoretical minimum amount of stress concentrations, thus producing stronger bends. This computer controlled machine accurately produces predictable and repeatable bends.

[0043] Although the present invention has been described with reference to its preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the true spirit and scope of the invention. In addition, many modifications may be made to adapt to a particular situation or material through the teaching of the invention without departing from its essential teachings. Some of these modifications may include, but are not limited to, having two linearly moving bending assemblies rather than one stationary and one moving, a driven and computer controlled means of reducing the linear distance between the couples 2, lever and cam clasps like a bicycle hub skewer quick release or an automated clamp to replace the material interface bolts 19, or the addition of an automated elongate material feeder and positioning system to reduce the work of an operator.